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**CENTRAL STATION
MARKET DEVELOPMENT STRATEGIES
FOR PHOTOVOLTAICS**

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DEVELOPMENT STRATEGIES FOR PHOTOVOLTAICS
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FINAL REPORT

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Meridian Corporation

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A B S T R A C T

The purpose of this document is to illuminate and analyze federal market development strategies designed to accelerate the market penetration of central station applications of photovoltaic energy systems.

Since no specific goals have been set for the commercialization of central station applications, strategic principles are explored which, when coupled with specific objectives for central stations, can produce a market development implementation plan. The major thrust of this document is concerned with developing methods of determining the appropriate federal role in this market through analysis of key issues and their relationship to strategy elements.

More specifically, this document includes (1) background information on the National Photovoltaic Program, photovoltaic technology, and central stations; (2) a brief market assessment; (3) a discussion of the viewpoints of the electric utility industry with respect to solar energy; (4) a discussion of commercialization issues; and (5) strategy principles.

It is recommended that a set of specific goals and objectives be defined for the photovoltaic central station program, and that these goals and objectives evolve into an implementation plan that identifies the appropriate federal role. In addition, certain unresolved issues are highlighted that need to be addressed before an implementation plan is developed.

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SECTION I

INTRODUCTION

A. PURPOSE

The purpose of this document is to illuminate and analyze federal market development strategies designed to accelerate the market penetration of central station applications of photovoltaic energy systems. Recommendations contained in this document are designed to be an integral part of the commercialization efforts of the National Photovoltaics Program. The objective of the Department of Energy's National Photovoltaics Program is "to reduce system costs to a competitive level in both distributed and centralized grid-connected applications. Equally important, the Program will also resolve the technical, institutional, legal, environmental and social issues involved in fostering widespread adoption of photovoltaic energy systems" (Ref. 15). The strategies proposed within can make a significant contribution toward the attainment of the overall Program objectives.

Since no specific goals have been set for the commercialization of central station applications, this document explores strategic principles which, when coupled with specific objectives for central stations, can produce a market development strategy. The major thrust of this document is concerned with developing methods of determining the appropriate federal role in this market through analysis of key issues and their relationship to strategy elements. This document does not address the details of strategy implementation. The strategies are discussed in general terms, with explicit but flexible timing issues addressed as appropriate.

It is assumed throughout this document that the Department of Energy's National Photovoltaic Program Plan remains in effect as described in the published Multi-Year Plan dated June 6, 1979. It is also assumed that other

photovoltaic market sectors are being addressed separately, so that the central station strategy need not be concerned explicitly with promoting these other applications.

B. BACKGROUND

Today, virtually all electricity generated in the United States is produced by large, central power stations fueled by conventional energy sources. As it becomes increasingly undesirable to utilize these sources to meet U.S. energy demand, new generating technologies will need to be explored. Solar photovoltaics is one such technology.

Photovoltaic energy conversion is a process by which electricity is produced directly from sunlight using a photovoltaic (solar) cell. The key advantage of photovoltaic technology is that it can provide safe, clean, renewable energy. Moreover, the long term potential and commercial feasibility for producing electricity from the sun by photovoltaics has already been demonstrated, through research, development, and demonstration efforts.

The major problem with photovoltaics is that it is expensive -- on the order of ten times the cost of conventionally powered electricity. In recognition of this problem, the Department of Energy's National Photovoltaic Program has set as the following objectives: (1) the reduction of photovoltaic system costs to a competitive level in the electric utility market; and (2) the resolution of technical, institutional, environmental, and social issues related to widespread adoption of photovoltaic energy systems.

On an absolute basis there are essentially two ways in which the cost of a new technology can be reduced. One method is through product improvement, which involves advanced research and technology development. The other is

through mass production. Product improvement can reduce costs to the point where demand will stimulate limited mass production, which will reduce costs even further, stimulating more mass production, and so forth. This theory is addressed as part of the National Photovoltaic Program.

Another approach is to reduce the relative cost of the technology, i.e., increase its worth. Regulation and financial incentive policies can contribute to increasing the worth of photovoltaics. These activities are discussed in more detail in later sections of this document.

C. THE NATIONAL PHOTOVOLTAIC PROGRAM

In addition to generic solar research and development legislation, the Department of Energy's National Photovoltaic Program is authorized by the Solar Photovoltaic Energy Research, Development and Demonstration Act of 1978 (Public Law 95-590), which appropriated \$1.5 billion over a ten year period. The appropriation was to provide for "an accelerated program of research, development and demonstration of solar photovoltaic energy technologies leading to early competitive commercial applicability of such technologies..." to enable this country to, in the long run, produce "electricity from photovoltaic systems cost competitive with utility-generated electricity from conventional sources."

As stated in the Multi-Year Plan dated June 6, 1979, the objective of the National Photovoltaic Program is "to bring photovoltaic energy systems, via substantial research, development and demonstration (RD&D) aimed at achieving major cost reductions and market penetration, to the point where they are able to supply a significant portion of the Nation's energy requirements."

As part of the National Energy Plan, which calls for renewable energy sources to supply 18 quads of primary energy by the year 2000, the Photovoltaics Program has set as its goal to displace 1 quad of fossil energy by the year 2000. Additionally, the following price goals have been set (in 1980 dollars) for photovoltaic systems:

- \$6-13/watt_p by 1982 for residential systems
- \$2.60/watt_p by 1986 for intermediate load centers
- \$1.30/watt_p by 1990 for central station applications

To meet these goals, a Photovoltaics Program strategy has been developed. The program strategy is directed towards the development of technologies and infrastructures that will yield technically, economically, and socially viable energy systems in primarily grid-connected applications. Key elements of the Photovoltaics Program Strategy include:

- Substantial reductions in the price of components and subsystems via:
 - aggressive advanced research and development to bring advanced concepts to the point of technical feasibility; and
 - intensive technology development to identify, develop, and suitably demonstrate cost-effective designs and production processes for components proven technically feasible, thereby establishing their technical readiness.
- Definition, development, design, and real-world testing of complete photovoltaic systems in a series of tests and applications to demonstrate (1) the system's feasibility; and (2) commercialization readiness.
- Development of a substantial body of experience, confidence, and expertise within the private sector by both users and suppliers of photovoltaic systems.
- Careful study and implementation of commercialization strategies.

The strategies to facilitate commercialization and market development are directed towards specific applications. The overall focus, however, will be directed towards triggering the creation of a new industry capable

of producing photovoltaic modules at a cost that would eventually compete with conventional sources. This will probably require the cooperation of utilities and manufacturers; however, private entrepreneurs are usually unwilling to risk the expenditure of major quantities of capital significantly far in advance of expected earnings. Thus, to accelerate the economic development of photovoltaics, government assistance will be imperative.

The program has identified five market sectors towards which specific market development strategies have been or are being developed:

- Remote/Stand Alone - Non-grid connected applications
- Residential
- Intermediate Load Centers - Community or business district entities
- Central Station - Electric utility power
- Federal Projects - To power federally owned facilities

Currently an international remote/stand alone market shows great promise, especially in the developing countries. An international photovoltaic market could contribute significantly toward developing a self-sustaining U.S. photovoltaic industry. However, the complete central station power plant market is the largest of all markets for photovoltaic electric power generation. It includes all electric power supplying utilities in the U.S., both generating and non-generating. For this reason, the preparation and execution of a strategy for central station market development is critical to the success of the Photovoltaics Program.

SECTION II

TECHNOLOGY AND APPLICATIONS

A. PHOTOVOLTAIC TECHNOLOGY

Of all of the solar technologies for converting sunlight into electricity, the one which intuitively is most desirable is photovoltaic conversion, because this technique requires no moving parts, no conversion to heat, and no evacuated vessels. Additionally, the basic scientific principles are well known, and for certain specialized applications the technology is relatively advanced.

Photovoltaic energy conversion is a non-thermal process in which electricity is produced directly from sunlight using a solar cell comprised mainly of a semi-conductor material, such as silicon, cadmium sulfide, or gallium-arsenide. The cells are made by combining two very thin layers of semi-conductor material. One layer demonstrates negative electrical properties and the other layer has positive properties. Terminals of an external electrical circuit are attached to the front and the back of the cell. When sunlight hits the cell, it causes the electrons of the cell to be freed. The freed electrons create voltage in the cell and the current can be drawn through the external circuit.

The photovoltaic cell described above is the basic component of any photovoltaic system. Most cells made today are produced from silicon wafers. Ongoing research and development efforts are directed towards bringing advanced silicon cells and cells made from other materials to technology readiness in hopes of reducing the cost of and increasing the efficiency of photovoltaic technologies.

Aside from defining the semi-conductor material from which a cell is fabricated, photovoltaic collectors can be categorized into two generic types:

- Flat Plate - Flat plate collectors are photovoltaic cells that are arranged in an array, lying in such a way such that they absorb sunlight as it is received. They are usually mounted in a fixed position because they have the capability to absorb light from nearly any angle. They also have the capability to generate electricity from diffuse as well as direct sunlight.
- Concentrating - Concentrators are magnifying lenses that are placed over rows of photovoltaic cells in order to increase the amount of light absorbed by each individual cell. They are usually mounted on computer-controlled tracking devices in order to keep the concentrators pointed directly at the sun. Although they provide a greater amount of electricity per unit of cell area than the flat plate collectors, they also only operate at maximum efficiency when properly oriented to the sun. In addition, since the concentration of light rays also produces significantly more heat, it is necessary to add an active cooling system to the concentrator array. However, the heat so generated may itself be piped off and used separately, in which case the array is called a "total energy" collector.

Although the basic photovoltaic technology is well understood, the generating of large amounts of electricity from sunlight is still in the developmental stages. As a result, the cost of generating electricity by photovoltaic energy conversion is commercially competitive only for a few specialized uses. However, rapid progress is being made in the technology and in methods for mass production of power-generation photovoltaic systems. Both government and private industry now predict that by 1986 photovoltaic technology will be available that can produce small scale electricity at a relatively competitive cost.

B. CENTRAL STATION SYSTEMS

A photovoltaic central station power plant consists of two basic elements: (1) the photovoltaic arrays and (2) the balance of system. The array is composed of photovoltaic cells; the balance of system includes everything else: support structures, a power conditioning unit, power transmission lines, optional storage, and a master control system which includes computer hardware, systems integration and operation software, and

trained operators. System sizes can range from hundreds of kilowatts to several hundred megawatts.

The critical component in any photovoltaic system is the array, which collects the sunlight and converts it to electricity. The array is composed of a number of electrically interconnected sealed panels (modules), each of which contains many photovoltaic cells. Because receiving arrays of varying sizes can readily be assembled by interconnecting electrically any number of sealed-panels, photovoltaic systems are inherently modular. For this reason, they are well adapted for dispersed or on-site applications, and for multiple uses. Photovoltaic systems, therefore, offer three key advantages:

- Modularity
- Low operation and maintenance requirements
- A proven technology

Because of the modularity of photovoltaics, there are no major technological differences between smaller stand-alone photovoltaic systems and the larger central station power plants. The larger plants will include more arrays, larger power conditioning and transmission equipment, and larger storage, which is both optional and modular. The major new features of the larger systems (as opposed to smaller systems or existing technology), are: (1) the master control system, (2) large scale power conditioning equipment, and (3) substantial storage, which is optional (but necessary if an individual system is to be included in the utility grid for purposes of determining the utility's capacity).

In 1990, advanced collectors are expected to cost \$.15-\$.40 per watt, thus bringing system costs down to \$1.10 to \$1.30 per watt for central stations. Collector costs are expected to be as low as \$.70 per watt in

1986, with system costs (for intermediate load centers) to be \$2.60 per watt. Today's system costs are in the range of \$15-20 per watt, about half of which is balance of system cost.

C. CENTRAL STATION APPLICATIONS

There are basically two types of central station applications: dedicated capacity and fuel savers. As dedicated capacity, the photovoltaic system can be used for either base, intermediate, or peak load operation. To insure on-demand operation for base or intermediate load applications, storage facilities or hybrid systems will be required. A central station fuel saver, however, would require no storage capabilities. Fuel saver central station systems are not depended on for additional capacity, but while the sun is available the use of a fossil fuel powered generator is reduced or temporarily replaced by the photovoltaic system. To implement fuel savers efficiently, the fossil fuel generator must be capable of starting up and shutting down, or altering its level of output, relatively quickly. Oil and gas fired steam generators can adjust quickly to such changes in the load. Nuclear and hydroelectric plants can also follow loads, but these are not considered as targets for replacement by solar energy. Coal plants do not load-follow well; the start-up time for a coal-system generator is as much as 6 to 8 hours.

The time ordered applications for dedicated capacity, therefore, is peaking, intermediate, and then base load.

SECTION III

THE MARKET SECTOR

A. MARKET ASSESSMENT

1. Market Definition

The complete central station power plant market sector includes all electric power supplying utilities in the U.S., both generating and non-generating. For the purposes of this plan, a central station is defined as a utility-owned facility designed primarily for generating electricity using photovoltaics technology, and serving a diversified load.

2. Market Size

The complete central station power plant market is the largest of all markets for photovoltaic electric power generation. The electric utilities consumed 31% (24 quads) of all primary energy in the U.S. in 1979, producing 2.25 trillion kilowatt-hours of electricity. In 1979 there were 545 gigawatts of electric generating capacity in the U.S (Ref. 14). It is anticipated that by 1989, an additional 233 gigawatts will be added, increasing the production capacity by 43% to 778 gigawatts (Ref. 14). Although this trend may appear to be a tremendous increase in capacity, especially in view of recent trends towards conservation, it is actually a slowdown in growth. From 1969 to 1979, production capacity increased by 74% from 313 gigawatts to 545 gigawatts.

Nearly half of our electricity was produced from coal in 1979, with oil, gas, nuclear, and hydro power each contributing an 11-15% share (see Tables 3-1 and 3-2). During the next 20 years, however, significant changes in fuel type usage are expected. Of all new generating capacity added in the next 10 years, 89% is expected to be coal or nuclear. This means that steps have already been taken to eliminate nearly all additions of oil and

TABLE 3-1. 1979 ENERGY CONSUMPTION FOR ELECTRIC UTILITIES IN THE U.S.

(Source: Monthly Energy Review, April 1980)

<u>Primary Fuel</u>	<u>Electric Utility Consumption In Quads</u>	<u>Percent of U.S. Sub-Total</u>	<u>Total U.S. Consumption In Quads</u>
Oil	3.53 (15%)	31%	37.04 (47%)
Gas	3.61 (15%)	18%	19.91 (26%)
Coal	11.28 (46%)	74%	15.15 (19%)
Nuclear	2.75 (11%)	100%	2.75 (4%)
Hydro	3.16 (13%)	100%	3.16 (4%)
Renewables	<u>0.09 (0%)</u>	<u>100%</u>	<u>0.09 (0%)</u>
	24.42 (100%)	31%	78.10 (100%)

TABLE 3-2. ELECTRICITY PRODUCTION AND GENERATING CAPACITY BY FUEL TYPE FOR 1979 AND 1988.

(Sources: Monthly Energy Review, April, 1980;
Inventory of Power Plants in the U.S. - April 1979, May, 1979)

<u>Primary Fuel</u>	<u>1979</u>		<u>Projected* Capacity Additions by 1988 (GWe)</u>
	<u>Utility Production (Billion KWH)</u>	<u>Utility Capacity (GWe)</u>	
Oil	304 (14%)	151 (26%)	15 (4%)
Gas	330 (15%)	75 (13%)	1 (0%)
Coal	1074 (48%)	229 (39%)	154 (45%)
Nuclear	255 (11%)	54 (9%)	151 (44%)
Hydro	280 (12%)	74 (12%)	21 (6%)
Renewables	4 (0%)	4 (1%)	3 (1%)
	<u>2247 (100%)</u>	<u>588 (100%)</u>	<u>346 (100%)</u>

*More recent projections call for an increase of only 233 GWe by 1989. A breakdown by fuel type was not available from the recent data. This chart is shown to display the planned emphasis on coal and nuclear.

gas powered facilities. Therefore, if photovoltaic central stations are to displace oil and gas plants, they must replace retired capacity or be used as fuel savers.

Private utilities produce most of our electricity, producing 78% of our power in 1978, with 11% each for public utilities and federal projects (see Table 3-3). This distribution is not expected to change significantly in the next 10 years.

3. Market Evaluation Criteria

The purpose of a market assessment is to highlight those market sectors that may be the target of particular elements of strategic market development strategies. This market assessment highlights entry and early target markets while providing a general evaluation of the market potential of other market sectors.

In order to illuminate these markets, four market evaluation classifications have been set up:

- Solar Availability - This criterion is measured by insolation values. The higher the insolation the greater the market potential.
- Primary Fuel Mix - Market sectors with high percentages of oil and gas capacity make better photovoltaic markets because (1) those fuels are scarcer, and (2) those fuels are relatively more expensive. Seven electric power sources have been identified, and are listed in descending order of the likelihood that photovoltaics could replace the fuel used to generate the power: oil, gas, non-generating (all power purchased), coal, nuclear, hydroelectric, and renewables.

TABLE 3-3. 1978 ELECTRICITY GENERATION AND CAPACITY BY TYPE OF UTILITY OWNER

(Source: Statistics of Privately Owned Electric Utilities in the U.S. - 1978, October, 1979)

	Installed Capacity (GWe)	1978 Production (10 ⁹ Kilowatt hours)
Private	445 (79%)	1721 (78%)
Public	61 (11%)	250 (11%)
Federal	54 (10%)	235 (11%)
	<hr/> 560 (100%)	<hr/> 2206 (100%)

- Market Growth - Some market sectors are growing faster or experiencing generating mix changes faster than others. Those markets with slow growth are less likely to require additional capacity or making mix changes than fast growth markets.
- Type of Ownership - Because of such factors as (1) the cost of obtaining capital, (2) regulatory requirements, and (3) profit requirements, type of ownership was selected as a market evaluation criterion. This classification has two possible characteristics: (1) Investor-Owned Utilities (IOU's) and (2) Publicly-Owned Utilities (POU's). Investor owned utilities, also known as privately owned utilities, are owned by stockholders. Publicly owned utilities include those electric utilities that are owned by state governments, municipal governments, cooperative associations, or any other sub-federal governmental entity. It is generally recognized that public utilities provide a better early market than do private utilities. The IOU's generally obtain capital (through borrowing or equity financing) at a higher cost, are subject to more regulation, and must maintain profits for their stockholders. POU's, on the other hand, can issue tax free bonds at a lower interest rate to obtain capital, are not regulated by most states, and have no profit requirements. The POU's, therefore, provide an earlier market because they can afford photovoltaics at a higher cost.

4. Market Segmentation

The market evaluation criteria described above are used to provide a rough measure of the market potential in various geographic areas. These geographic areas were selected to illuminate the differences among central

station market sectors with respect to these criteria. The ten market sectors selected are:

- New England - Connecticut, Rhode Island, Massachusetts, Vermont, New Hampshire, and Maine.
- Middle Atlantic - New York, Pennsylvania, and New Jersey.
- East North Central - Wisconsin, Michigan, Illinois, Indiana, and Ohio.
- West North Central - North Dakota, South Dakota, Minnesota, Nebraska, Iowa, Kansas, and Montana.
- South Atlantic - West Virginia, Maryland, Virginia, North Carolina, South Carolina, Georgia, and Florida.
- East South Central - Kentucky, Tennessee, Mississippi, and Alabama.
- West South Central - Oklahoma, Arkansas, Louisiana, and Texas
- Mountain - Montana, Idaho, Wyoming, Nevada, Utah, Colorado, Arizona, and New Mexico.
- Pacific - Washington, Oregon, California
- Hawaii and Puerto Rico.

5. Market Evaluation

Based on the market evaluation criteria described above, early markets for photovoltaic central station applications can be identified as the publicly owned oil and gas markets in areas of high insolation and rapid load growth. For fuel saver applications, load growth is not as important, since the photovoltaic system will not be considered in determining the capacity of the utility.

The two most important factors for the earliest markets are dependence on oil and gas, and solar availability. These two factors have the greatest effect on the value of solar energy. As oil prices increase and photovoltaic prices decrease, however, solar availability may not be such an important factor in service areas dominated by oil and gas fired utilities, since photovoltaics may become competitive with oil even in lower insolation areas.

The issue of public versus private ownership may also decrease in importance after the early markets are penetrated. This is because, after a few central station plants have been operational, privately owned utilities (1) will feel more confident in investing stockholders' equity in solar energy, (2) may encounter regulatory encouragement at the local level, and (3) will be able to purchase photovoltaics at a lower price (than the early market price), thus reducing the effect of higher interest rates.

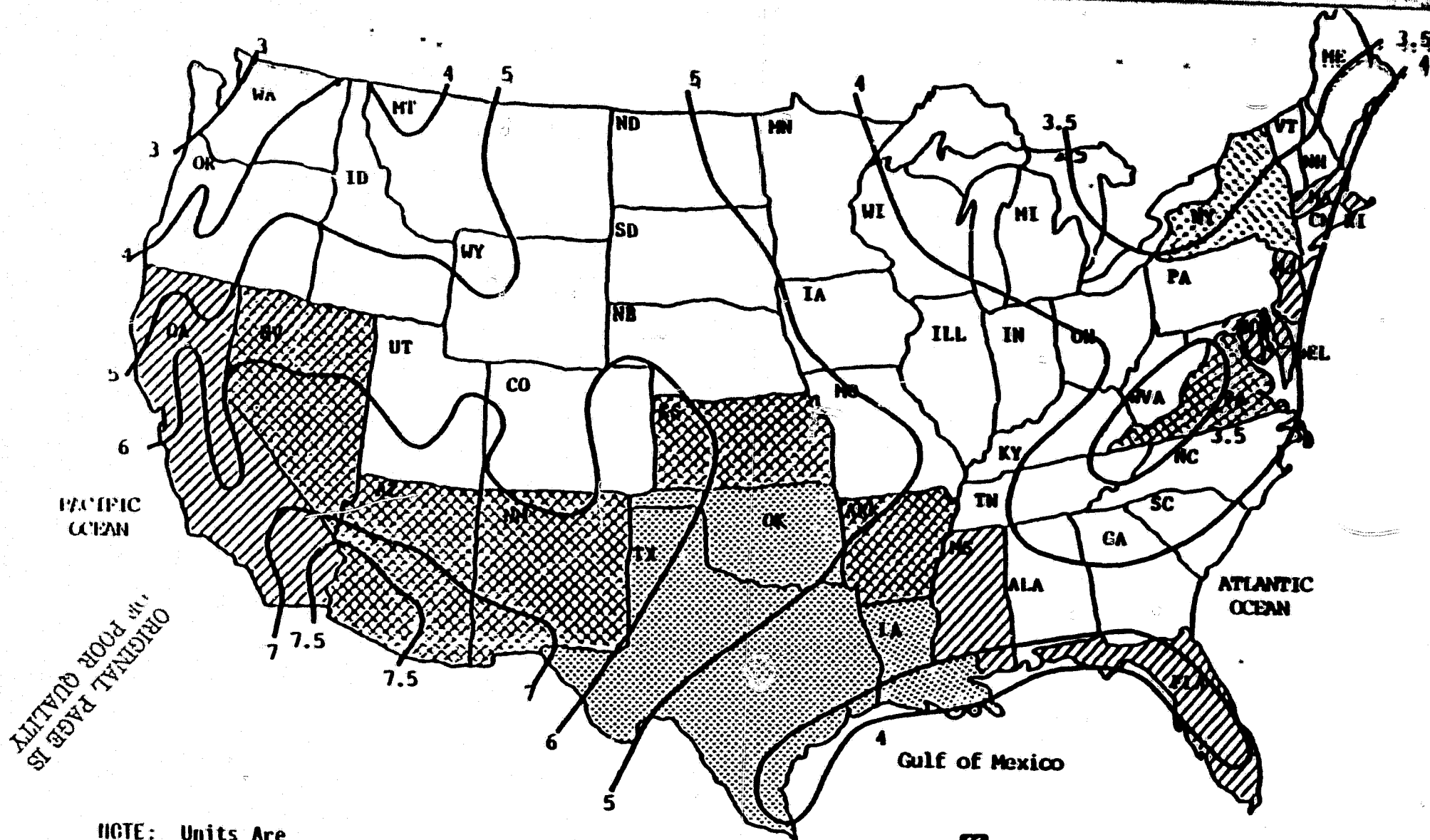
Load growth, on the other hand, will play a more significant factor in post-early market penetration. This is because early markets are likely to be fuel saver applications, which are independent of capacity requirements. For long term growth, however, photovoltaic systems must supply capacity credit. The growth factor therefore, is considered to be less of an early market indicator and more of a long term market indicator.

The ten geographic central station market sectors can be evaluated as follows (see Table 3-4 and Figures 3-1 and 3-2; source Ref. 7):

- New England - Even with its heavy dependence on oil and gas, New England is not likely to provide a significant early market. Its insolation is too low, and it has few public utilities. As a result, New England is turning rapidly towards coal and nuclear power. For example, despite the recent problems experienced in the nuclear industry, the state of Maine, in response to a voter referendum, elected to continue its trend towards nuclear. The impact of this development on photovoltaics is that it might not be competing with oil or gas, but with coal and nuclear. Consequently, if photovoltaics fails to penetrate the oil and gas market by the early nineties, there may not be such a market left to penetrate.

TABLE 3-4. MARKET SECTOR EVALUATIONS

Region	Daily Solar Insolation (KWH/m²/day)	Dependence On Oil & Gas	Public Owner- ship	Projected Load Growth 1979-1989
New England	3.0-4.0	55%	3%	21%
Middle Atlantic	3.5-4.0	29%	9%	23%
East North Central	3.5-4.5	5%	8%	38%
West North Central	4.0-5.5	8%	31%	48%
South Atlantic	3.5-4.5	25%	9%	50%
East South Central	3.5-4.5	9%	62%	45%
West South Central	4.0-6.0	85%	11%	58%
Mountain	4.0-7.5	14%	33%	51%
Pacific	3.0-7.5	33%	60%	51%
Hawaii & Puerto Rico	6.0-7.5	99%	75%	13%



NOTE: Units Are
KWh/m²/day

- States Burning ≥ 56% Oil in 1978
- States Burning ≥ 50% Gas in 1978
- States Burning ≥ 25% Oil and Gas Combined in 1978

Direct Normal Insolation Availability Compared With Current
Fuels Consumed by Utilities

Figure 3-1

Figure 3-2

- Middle Atlantic - This region is similar to the New England region, but with even less of a dependence on oil and gas. Although this region is a bit more reluctant to use nuclear, it is rapidly converting to coal. Thus, this region receives the same prognosis as New England.
- East North Central - This area has low solar availability, little dependence on oil and gas, and few publicly owned utilities. As a result, this area has little or no prospect for large scale solar energy in this century.
- West North Central - This area has low solar availability and little dependence on oil and gas. The southern portion of this region, however, has a higher solar availability and a greater dependence on oil and gas. Individual states, such as Kansas and Missouri, may provide a market for central station photovoltaics.
- South Atlantic - This area has some high solar availability, a significant dependence on oil and gas, and a projected load growth that is rapid. However, it has little public ownership. While this sector is not likely to be an entry market, it will develop rapidly following successful entry market penetration elsewhere.
- East South Central - The Tennessee Valley Authority's presence in this area creates a unique issue -- what is the role of federal power projects in the marketing of solar power?
- West South Central - With an 85% dependence on oil and gas, high insolation, and a rapid capacity growth in its future, this area could provide a significant early market for

photovoltaic central stations. Even though only 11% of the capacity in this area is owned by the public, that 11% should provide an early market.

- Mountain - Relatively high insolation levels, publicly owned utilities, and load growth are available in the southern mountain region. Its dependence on oil and gas, however is not significant. In fact, this area uses mostly inexpensive coal. However, Arizona and New Mexico each have developed a significant dependence on oil and gas, and historically have been receptive to solar energy technologies. With proper federal incentives, these two states could provide a prime early market for photovoltaic central station power.
- Pacific - All indications are that the Pacific region is the prime market in the continental U.S. This area is depending heavily on hydroelectric power for growth, but in some areas there is not enough hydroelectric power or it comes with expensive water control requirements. In fact, hydroelectric power can be expensive unless the government funds the dam from recreation funds, water resource funds, or transportation funds. This is evident by the recent statement by a publicly owned California utility that claimed its breakeven cost for photovoltaics is \$2.70 watt -- in competition with hydroelectric power. This situation appears to be unique to the west coast, where coal is not burned, nuclear power is discouraged, oil and gas are expensive, and available hydroelectric resources are already being utilized.

- Hawaii & Puerto Rico - These islands exhibit market characteristics that are conducive to solar power. Moreover, there is a generally positive, and in some case aggressive, attitude towards solar.

B. UTILITY VIEWS

Among the entire electric utility industry there exists a general lack of knowledge of photovoltaic power technology. There are some utilities, however, in regions of the country identified as early markets, where there exists at least a monitoring of solar energy developments. Most of these utilities view photovoltaics as an expensive, unproven technology whose practical use is at least a decade away.

Despite this attitude, interest in solar energy is growing within the utility industry. More and more southwestern and west coast utilities are watching the development of central station solar power. One California municipal utility is actually seeking government assistance, in the form of price guarantees, in building the nation's first large central station photovoltaics plant.

Several electric utility surveys have been conducted to establish the conditions under which the utility industry would buy photovoltaics. The consensus is that a demonstration or commercial plant must operate successfully for 3-5 years in a grid connected central station application before most utilities will consider photovoltaics a technologically proven system for central station applications. There is disagreement over the size of this plant: desired sizes range from one megawatt to 50 megawatts.

There are several good reasons why the utilities are insisting on this demonstration of the technology:

- Unknowns concerning photovoltaics necessitate prudence by utilities, which must provide reliable power at a reasonable cost.

- Although photovoltaics is a relatively benign technology with respect to safety and the environment, lack of data on long term environmental impacts arouses caution.
- Utilities are not convinced that estimated construction lead times are adequate.
- The mode of operation of an intermittent power source is a point of concern that requires operational experience to validate.

The utilities must satisfy three basic constraints:

- Provide reliable power
- Conform to Public Utility Commission (PUC) regulations and rulings
- Maintain a credit rating and profit rate that allows the utility to be able to obtain capital for new generating capacity.

These three constraints tend to work against the early market penetration of photovoltaics. The reliability of solar power has not been proven to be comparable to that of conventional power. Solar power is not perceived as a sound investment by the financial community. Public Utility Commissions are reluctant (sometimes due to consumer pressure groups) to allow ratepayers to fund expensive solar experiments.

On the other hand, there are a number of factors limiting the use of conventional power. The barriers to solar utilization must be balanced against these impediments, which are discussed below.

1. Legal Restrictions on Gas and Oil

The Power Plant and Industrial Fuel Use Act of 1978 prohibits the installation of new gas or oil fired capacity. Although there are exceptions in this law, it has generally been effective in limiting the use of those scarce fossil fuels.

2. Long Lead Times

Because of complicated licensing procedures and long construction periods, it usually takes 7 to 10 years to build a coal plant, and 12 years for a nuclear plant. This limits the speed with which utilities can convert from oil and gas to coal and nuclear power. More importantly, most PUC's do not allow construction work in progress in the rate base, which means a plant must be operating before the utility can begin to receive a return on its investment. The modularity and short lead times of photovoltaics can alleviate these two problems.

3. Resistance to Nuclear Power

The Three Mile Island incident has increased popular opposition to nuclear power. Many states are not allowing the addition of any nuclear plants. In those states that allow nuclear power, new license applications are consistently being challenged by the adversaries of nuclear power.

4. Regulatory Limits on Coal

Environmental standards for clean air are gradually becoming more stringent. The recently amended Clean Air Act, as well as many individual state regulations, result in a more difficult licensing and inspection process, as well as in more expensive coal plants.

SECTION IV

COMMERCIALIZATION ISSUES

An understanding of the central station market sector -- and the principal issues and barriers associated with that sector -- is essential to the formulation of photovoltaic central station market development strategies. It is the purpose of this section to identify and illuminate the range of issues which will impact central station commercialization efforts.

The primary issue areas that must be considered in preparing a market development strategy for photovoltaic central stations relate to the high cost, high risk, and implementation barriers associated with this technology. Specific issues that will be addressed with respect to each of these areas are summarized in Table 4-1, and are discussed in detail in the following paragraphs.

A. ECONOMIC BARRIERS

The cost of photovoltaics is the greatest obstacle to the achievement of the overall objectives of the National Photovoltaic Program. An installed photovoltaic system today would cost from \$10-\$20/peak watt, which is several times larger than the \$1.10-1.80/peak watt price needed to be competitive with petroleum power. The cheapest system bid to date was a \$16/watt bid on a PRDA system in 1979. One company, however, claims that it could install the first megawatt of a 100 MWe system for approximately \$10/watt in 1981. These cost estimates are not only high, but they contain a great deal of uncertainty since no central station photovoltaics plant has ever been built. These high initial investment costs, coupled with high interest rates, currently make photovoltaic systems economically unattractive.

TABLE 4-1. PHOTOVOLTAIC CENTRAL STATION ISSUE AREAS

A. ECONOMIC BARRIERS

1. Modules
2. Balance of System
3. Utility Worth
4. Financing

B. TECHNOLOGICAL RISK

1. Lack of System Experience
2. Lack of User Awareness and Confidence

C. IMPLEMENTATION BARRIERS

1. Materials Availability (Silicon)
2. Lack of Industrial Infrastructure
3. Lack of Standards and Codes
4. Large Land Requirements
5. Environmental Impacts
6. Legislative Requirements

There are four aspects to the problem of high cost of photovoltaic central stations, each of which will be addressed individually. These include the cost of the modules, the cost of the balance of the system, the worth of photovoltaics to the utility, and financing. The factors affecting each of these aspects, and potential policies that could alleviate specific problems, are considered in this section.

1. Cost of Modules - Photovoltaic modules are the building blocks from which photovoltaic electricity is derived. Currently, a major cost of photovoltaic modules is in the silicon used. The development of processes to reduce the cost of single crystal silicon is the single most important element of a strategy to reduce the cost of photovoltaic modules, although the establishment of an automated production plant would also decrease the cost of delivered modules. However, the opportunity to reduce the cost of modules through mass production depends upon the existence of sufficient demand; yet the demand is not likely to develop without a reduced cost for modules.

The federal role in inducing cost reductions through mass production needs to be defined more precisely. The stimulation of mass production in order to enable a reduced cost for photovoltaics has been and will continue to be a key element of the National Photovoltaic Program's strategy. By applying a combination of financial incentives (discussed below under Balance of System) to producers of photovoltaic modules, the federal government could enhance production in all periods considered in this document.

The stimulation of mass production in the very near-term would probably require the federal purchase of mass production facilities. These facilities could then be transferred to private industry ownership through any of a number of mechanisms for lease and/or delayed purchase for subsequent operation

and ownership. Although this would require a large federal outlay, significant leverage would be returned for those dollars. First, cost reductions for photovoltaic cells would be realized immediately. Second, mass production techniques would be established and in practice. And last, but not least, the private sector would assume the responsibility for marketing photovoltaic systems. Consequently, the potential leverage from federal dollars invested in such a plan deserves serious consideration. However, such a plan would require a silicon production plant as well, which may not be cost-effective in the mid-term (see discussion under Materials Availability).

Reducing cost in the mid- or long-term can best be accomplished through (1) technology development and (2) research and development. Efforts in R&D are already underway in the National Photovoltaic Program, and no additional efforts are required explicitly for central station market development. A technology development effort for central station, on the other hand, would be beneficial to a strategy targeted at the mid-term market expansion. Such an effort should concentrate on the industrial engineering problems of establishing a module manufacturing plant.

2. Balance of System - Although reducing the cost of photovoltaic central stations is highly dependent upon reducing the cost of modules, an important consideration for central station applications is the cost of the balance of the system. The balance of the system for central station applications includes land, structures, transfer equipment for both direct and alternating current, inverters, optional storage equipment, and electric plant equipment for switching, power conditioning, plant controls, and protective features. In the long run, as the cost of modules decreases, the

cost of the balance of the system will assume greater significance. Development of innovations/cost reductions for balance of system components is oriented toward improving system reliability and cost effectiveness in the long run.

However, in the near-term, there are two fundamental types of actions that could result in significant reductions in the cost of photovoltaic central stations. First, financial incentives at the federal level to produce or sell photovoltaic central station systems would reduce the effective cost of photovoltaics and, if significant enough, stimulate the purchase of hardware. Second, an increase in the production of these systems would reduce cost and result in further market penetration.

There are four types of federal financial incentives which could readily be pursued that would have a favorable impact on the cost of both photovoltaic modules and the balance of system components.

a. Direct Grants

Direct grants could purchase an entire system or be part of a cost sharing or risk sharing program. In either case, direct grants have produced the most dramatic cost reductions, but can only be applied to a small segment of the market. Direct grants, therefore, are best suited for demonstration projects or targeted for early commercial systems, where such market stimulation could lead to an accelerated commercialization of the most promising market.

b. Direct Loans

Even when photovoltaic systems are nearly competitive with conventional alternatives on a life cycle cost basis, photovoltaic systems will still require a large initial capital outlay. In an economic environment characterized by high interest rates, a low interest federal loan would

bring photovoltaics to an economically competitive level sooner than if commercial interest rates prevailed. The best time for these loans would be when cost analyses indicate that the lower interest rate would make a significant difference in the advisability of photovoltaics for a specific market. Future market studies are necessary to indicate the best time for such loans. In any case, their timing will depend on the amount of loans available, the cost of photovoltaic and alternative energy systems, the commercial interest rate, and the status of other barriers.

c. Loan Guarantees

The next best thing to a direct loan is a guaranteed loan. The federally guaranteed loan can reduce risk to the lenders, and thus reduce interest rates. Although these interest rates will be much higher than for a direct loan, they can be applied on a much larger scale, since no initial federal outlay is required (and possibly no outlay at all). As with direct loans, the initiation of federally guaranteed loans should be timed to get the most leverage out of the market environment.

A major difficulty with loan guarantees instituted on a broad scale for central station photovoltaics is that, depending on the success of photovoltaics, the loans are likely to be either totally repaid or totally defaulted on, which compounds the risk to the government.

d. Tax Credits

Tax credits have already been applied to small scale solar energy projects. Tax credits are a form of cost sharing, but are unique in that no initial capital outlay is required. Rather, the only loss is that of future revenue. Tax structures for electric utilities are far more complex than for small users, however. The applicability and effectiveness of federal tax credits for central station applications requires further study.

e. Price Guarantees

Price guarantees are a useful technique to obtain a long term commitment to photovoltaics. This commitment also serves to establish sufficient demand for photovoltaics so that an industrial infrastructure can develop. This development would then facilitate the fall of system prices enabling the market to obtain long range equilibrium characterized by significantly lower prices and higher demand than that which prevails currently.

The essence of this method is to utilize the projected long range declining prices of photovoltaics in comparison to the long range increasing prices of conventional technologies. The federal role in this mechanism is to guarantee the utility that photovoltaic prices will actually fall in the future as predicted. The utility can then conduct its cost analysis in an atmosphere of diminished economic uncertainty. The benefit for the utility is a guaranteed long term cost of energy; the benefit for the National Photovoltaic Program is the opportunity to commercialize photovoltaic systems faster than would occur in the absence of price guarantees.

By its nature, this technique will yield its most dramatic results as a short-term strategy, since eventually photovoltaic systems should be competitive in the free market and will require no price guarantees.

3. Utility Worth - The worth of photovoltaics to utilities encompasses a broad range of issues related to the cost of acquiring photovoltaics in relation to the cost of not acquiring photovoltaics.

One of the key features of utility worth is the calculation of busbar costs of electricity. This calculation is in itself not necessarily straightforward, since several factors and assumptions must be quantified

that will vary among utilities. These factors include the capital structure of the utility, the cost of capital, the income tax rate, investment tax credits, property taxes, depreciation method for tax purposes, inflation rates, and escalation rates for the means of production. These inputs will vary depending upon the nature of the utility and its location. For example, public utilities are not required to pay taxes, and can obtain capital at favorable rates compared to private utilities. In addition, methodologies for determining levelized busbar costs do not always produce comparable results. Consequently, the determination of even the most fundamental element of utility worth analysis may not yield unambiguous results when applied to the analysis of photovoltaics. For this reason, it is important that a consistent, thorough, and reliable methodology be developed that includes both economic and non-economic factors and accurately evaluates the worth of a photovoltaics central station plant to an electric utility uniformly. The technique should be formulated to be acceptable to both the utility industry and to DOE.

In addition to the costs of producing electricity, procedures must be incorporated into the utility worth analysis to assess the true worth of photovoltaics by including factors that are beneficial yet unique to photovoltaics (and consequently are generally not considered). For example, a distinguishing characteristic of photovoltaic central stations is their modularity. This modularity may provide the benefits of improved generation planning, which should have a quantifiable worth to a utility over and above levelized busbar costs. Currently, an electric utility must conduct complex generation planning exercises to meet capacity demands which must be estimated 5-12 years in advance of the installation of conventional power plants. Because of trends towards economies of scale, utilities often put

in large plants before the entire capacity is needed, but long after some of the capacity is needed, resulting in a cyclical variation between peak load and peak capacity. Virginia Electric and Power Company, for example, was one GWe short in 1972 and 1973, but was 1-2 GWe in excess each year from 1974-1977 (Ref. 19). The Sacramento Municipal Utility District was 400-600 MWe short from 1972-1975, but was 200-300 MWe in excess from 1976-1978 (Ref. 19) due to the installation of a 914 MWe nuclear plant in 1976. With photovoltaics, a utility can add capacity incrementally, thus simplifying much of the generation planning and its related problems.

Another potential effect of the modularity of photovoltaics is that economies of scale are not as significant as for conventional power. Although some reduced costs per kW have been quoted for larger plants, they may be outweighed by the advantages of operating smaller plants. Some of these advantages may have not been previously considered. For example, when a utility operates several small plants instead of a few large plants, the total capacity requirement is reduced. This phenomenon is attributed to the reduced reserve requirement that arises from the reduced probability of the loss of a large generating unit (Ref. 27). Transmission and distribution costs (currently estimated at 10% of O&M costs) and losses may also be reduced when plants are dispersed. Construction times may be shorter for smaller plants, thus providing savings in capital cost during construction. The question of whether photovoltaic central stations can be applied to the capacity requirement remains to be resolved.

An additional attribute of modularity which should be of particular importance to private utilities is that a utility that adds photovoltaic capacity incrementally does not require large amounts of capital to be dedicated to the construction. Since utilities are not permitted to obtain a return on funds used during construction, this aspect should serve to increase the worth of photovoltaic systems.

As a result, this phenomenon not only permits generation planning to incorporate the results of shorter-term market forecasts, but also enables the utility to exercise more stringent financial management.

Finally, a determination must be made concerning the worth of fossil fuel displacement as a desirable policy irrespective of purely economic criteria. The inclusion of such a judgment in a worth analysis may be justified based upon national energy policy and the inherent unpredictability of fossil fuel prices. The worth of less variable prices for photovoltaic systems (assuming a federal price guarantee or similar funding mechanism for short run commercialization) should be evaluated.

A study of these potential advantages of photovoltaic central station plants, which should also include an analysis of whether or not the utilities would welcome such advantages, could further illuminate the advantages of photovoltaics and increase its worth to utilities.

4. Financing - The investment in a 50-100 MWe central station facility will require significant amounts of capital. Financing the large capital investment required for a photovoltaic central station will be particularly difficult for early market penetration, due to the high level of perceived risk associated with this technology.

The major issue that needs to be resolved with respect to photovoltaic central station financing is the federal role in providing insurance against losses to reduce risk. Several options are available to the government. A straightforward option is the direct federal financing of photovoltaic central stations, which can be accomplished through grants, loans, federal purchases and tax credits, or loan guarantees, as described in previous sections. Although this method is the most direct approach to photovoltaic commercialization, it is also one of the most costly, requiring capital outlays in the short run.

The government possesses other powers that can be wielded to effect the commercialization of photovoltaic central stations indirectly by making financing more attractive to other parties. For example, legislative requirements enabling the prompt introduction of photovoltaic systems into a utility's rate base would make photovoltaics a viable alternative for private utilities, particularly if federal intervention precluded local regulatory penalties for system failures during start-up phases. Similarly, redefining photovoltaic central stations as part of a utility's capacity requirement would supplant the need for conventional capacity expansion, freeing private capital for investment in photovoltaics. The use of such legislative initiatives, used in tandem with other fiscal alternatives, should be examined as techniques to facilitate the market development of photovoltaic central station.

B. TECHNOLOGICAL RISK

Equally important as the economic considerations are the issues associated with the technological risks of photovoltaic central stations. Although the basic photovoltaic cell is a technologically proven device, its application in central station electric power plants is considered (by the electric utility industry and the financial world) a high risk venture. This is simply because no photovoltaics central station power plant has ever been built or operated. These technological risks exacerbate the economic risks discussed previously, since cost reductions in photovoltaics resulting from anticipated breakthroughs are difficult to forecast precisely. In addition, the danger exists that the industrial infrastructure required to maintain and operate a plant will not be available. Whether or not these risks are substantial, they are real in the sense that they

are perceived by the electric utility industry and financial institutions, which comprise the market for photovoltaic central stations.

Historically, utilities have been financially conservative since their service records and rates of return are closely scrutinized by public agencies. Consequently, some impetus must be provided by the federal government to provide utilities with sufficient incentives to overcome the fundamental inertia of this market. Diminishing technological risk is a major activity in such a strategy. The problem of technological risk is discussed below with respect to both the requirements for systems experience as well as with respect to the need to provide individuals with information on the capabilities and reliability of photovoltaic systems.

1. Lack of Systems Experience - Most electric utilities require data on the operational characteristics of a 50-100 MWe plant over a 3-5 year period before they would consider investing in photovoltaics. By this reasoning, such experience would provide the utilities with sufficient information on reliability, cost, usage, operating and maintenance, and other data, which would reduce the technological risk.

A major consideration that must be resolved in a market development strategy is the difficulty that an electric utility would have in integrating a photovoltaic system into the conventional grid, even if such systems were available and cost-effective. This difficulty is a direct consequence of the lack of systems experience with photovoltaic central station applications. First, the infrastructure to support the installation and maintenance of a photovoltaic facility is not intact, and as a result the acquisition of these services imposes both a cost and a risk on the utility that first adopts photovoltaics. Second, the operator training required for a facility

powered partly by solar energy is not available, so the utility risks service interruptions.

The most promising technique for eliminating this commercialization barrier is for the government to assume a portion of the risk through demonstration projects of commercial systems. The operational experience gained from such projects must then be thoroughly monitored and carefully recorded to insure maximum benefits to utilities. In addition, the knowledge of the system characteristics acquired through these projects must be disseminated throughout the appropriate market sectors. In this manner, the demonstration projects would also help to alleviate user awareness problems, which also tend to augment the perceived technological risk.

2. Lack of User Awareness of and Confidence in Photovoltaics - This particular barrier is most serious in the near-term, since it threatens to hamper the initial commercialization of photovoltaics in central station applications. Several electric utility surveys have indicated that there is a general ignorance of solar energy in the utility industry. Although this individual factor by itself is not preventing any commercial buys currently, in a few years when systems reach early market competitiveness this barrier could stunt market growth.

The tremendous effort required to get systems to a competitive level should not be wasted because of a lack of information and communication. What is needed to overcome (or prevent) this barrier is a powerful information dissemination program, coupled with the appropriate demonstration projects, in order to keep abreast of the rapidly advancing technical developments. This program should include collecting data from operating photovoltaic systems and actively disseminating this information within the central station market segments that are considered penetrable by photovoltaics.

Specific functions of this program should be designed to provide data, technical facts, contractor names, standards and codes information, general photovoltaic information, and possibly mobile mini-demonstration projects.

In order to be most effective, this information program needs to include the following elements:

- Data Accessibility - The program must have easy and expedient access to the technical knowledge and field performance data that is collected by the field offices and laboratories. This element of the program is crucial to the public image and understanding of the Photovoltaics Program.
- Data Consistency - The data disseminated by this program must be collected and assembled in a common format. Otherwise, the performance of different systems will be difficult to compare; and potential users may become confused and disenchanted with photovoltaics. This data consistency effort will require cooperation from the field offices and the laboratories, and coordination by the Tests and Applications Branch of the Photovoltaics Program.
- Interactive Information Flow - A mechanism for distributing the information must be interactive and thorough in its approach to reach all potential users. Additionally, the mechanism must be able to accept feedback from industry (and respond to this feedback) so that industry recommendations for improving this or any part of the Photovoltaics Program can be considered.
- Mobile Demonstrations - A few small arrays that can be transported around the country could serve several purposes. First, the arrays would give a firsthand display to potential users that the system works. Second, it would help to familiarize industry with the

system and its components. Finally, the mobile demonstration project could be used to provide site specific solar availability data.

In addition to the elements listed above, a possible extension of the information program could include a product test and comparison project. This project could offer to test (free of charge) any commercial component of a photovoltaic system. The test results could be published in a clear, concise form that would allow a user to compare competing components. This project would have three distinct purposes:

- provide potential users a mechanism for "shopping" for photovoltaics
- maintain general quality control in the photovoltaic industry
- contribute to the adoption of industry-wide standards and codes for photovoltaic systems.

C. IMPLEMENTATION BARRIERS

In addition to the issues relating exclusively to cost and risk, there are also a number of issues that need to be addressed by the National Photovoltaics Program in order to implement central station photovoltaic applications. These issues range from the problems of developing an industrial infrastructure to accommodate the photovoltaics industry to legislative and programmatic factors that must be considered in preparing a market development strategy. Each of these issues is considered individually below.

1. Materials Availability - The availability of materials for photovoltaic central station applications presents a barrier to the attainment of commercialization goals only insofar as there exists a shortage of materials for module production. The materials required to manufacture the balance of

system components -- including structure, DC and AC wiring, power conditioning equipment, control stations, and storage equipment -- are generally obtainable when necessary. The predominant barrier to mass production of modules is the availability of sufficient quantities of polycrystalline silicon.

The availability of silicon is problematic for two basic reasons. First, there exists a competition for supplies with integrated circuit manufacturers who require large amounts of the material for semiconductors. The integrated circuit industry is projected to exhibit continued growth over the next few years, with no significant private investments in new silicon manufacturing capacity planned. This phenomenon should place additional strains on existing capacity.

Second, there are new technologies being developed under federal contracts to produce polycrystalline silicon less expensively than current processes. For this reason, investments in conventional production capacity are uneconomical, requiring depreciation of equipment over a shorter period of time than historically. In addition, the cost of new silicon production equipment has increased since the technology was first introduced.

Consequently, conventional polycrystalline silicon manufacturing equipment is at present a technology that is about to become obsolete, and yet is depended upon by both the integrated circuits industry as well as by the emerging solar cell industry. The impact that this development will have on central station photovoltaic applications is dependent upon the response of private industry to any perceived materials shortages. At worst, the problem will affect the ability to produce photovoltaic modules in the near term only, thus delaying the achievement of PV Program goals. At best, the shortage will not develop as predicted.

There are several options open to DOE for responding to any anticipated shortages. For example, DOE could simply allow the market to dictate the availability and price of silicon. Alternatively, the government could offer joint financing/ownership of new silicon manufacturing equipment with companies that would also require it. Finally, the government could construct silicon processing plants on its own to provide only the silicon necessary to meet its own goals, expensing the cost of the equipment.

It is not unreasonable to expect some of the required materials to be provided from private sources. A recent projection of polycrystalline silicon supply and demand is shown in Table 4-2 (Ref. 16). As shown in this table, the non-solar market demand is expected to outstrip supply even if no photovoltaics are installed. Therefore, the integrated circuit and power device industries are facing a shortage regardless of whether additional silicon capacity is constructed. As stated previously, these industries are reluctant to invest in new capacity since federally-funded research and development programs are expected to yield significantly less expensive silicon manufacturing processes by 1986. The cost of manufacturing silicon using the old process in a new plant is shown in Table 4-3 (Ref. 16).

As noted in Reference 16, polycrystalline silicon at this cost is approximately 1% of total manufacturing cost for the integrated circuits industry; for photovoltaics the percentage is significantly higher. Hence, manufacturers of integrated circuits can afford to pay more for silicon than the photovoltaics industry.

The manufacturers of integrated circuits therefore are caught in a dilemma. They are aware that the government is developing processes to reduce the cost of silicon by 1986. At the same time, they ought to be

TABLE 4-2. POLYCRYSTALLINE SILICON (SOLAR AND NON-SOLAR): COMPARISON OF CAPACITY AND MARKET NEEDS FOR HIGH FORECAST (METRIC TONS)

<u>Year</u>	<u>Non-Solar Market</u>	<u>Solar*</u> <u>Market</u>	<u>Total Market</u>	<u>Capacity to Produce</u>	
				<u>Without Non-Con- forming**</u>	<u>With Non-Con- forming**</u>
1977	1128	8	1136	2105	2420
1978	1533	16	1550	2129	2459
1979	2042	60	2102	2270	2610
1980	2357	122	2479	2695	3100
1981	2680	211	2891	2885	3320
1982	3056	420	3476	3050 shortage	3510 shortage
1983	3415	816	4231	3145	3615
1984	3815	1580	5395	3195	3675
1985	4220	2760	6980	3245	3775

*For PV power capacity required by Public Law 95-590.

**Non-conforming to integrated circuits industry specification.

**TABLE 4-3. COST OF MANUFACTURING POLYCRYSTALLINE SILICON NEW PLANT -
OLD TECHNOLOGY (SIEMENS)**

Power at \$0.03/kwh	\$ 8.00/kg
SiHCl ₃ at 3 cents/gram	17.00/kg
H ₂ at \$0.80/100 cu. ft.	2.00/kg
Supplies	4.00/kg
Maintenance and Engineering	4.00/kg
Wages	2.50/kg
Salaries	1.00/kg
Miscellaneous	1.50/kg
Depreciation 10 years straight line	<u>20.00/kg</u>
Cost	\$60.00/kg

aware of the supply/demand forecasts of Table 4-2. Faced with both of these projections, executives of integrated circuiting manufacturing concerns are faced with two choices. They must either secure a supply of silicon (presumably at a price significantly higher than will prevail in 1986) or else allow a silicon supply disruption to adversely impact their ability to conduct their business. Since silicon accounts for only 1% of manufacturing costs, it seems likely that private manufacturers will secure their supply rather than disrupt their operations. In fact, from the perspective of such manufacturers, depreciating a plant over 4 years rather than 20 years would increase the cost of silicon from \$60/Kg to \$90/Kg, which would increase the cost of their product about 1/2 of 1%. Compared with the costs of being at a severe competitive disadvantage in the integrated circuits market for 2-3 years due to a silicon shortage, the investment in a secure source of silicon would seem attractive, even if the equipment became obsolete by 1986.

Consequently, one would expect the supply of silicon to the integrated circuits industry to be sufficient to meet the demand, even in the absence of technological breakthroughs. The price at which silicon will be available to this industry remains uncertain.

The demand for silicon by the solar market is dependent on the price of silicon. Three demand forecasts show dramatically different requirements for the solar market. These forecasts are shown in Table 4-4. Historically, about 15% of the non-solar market demand has not conformed to the industry standards (and as a result has been available to the solar market). Therefore, one might expect about 633 metric tons of silicon (15% of 4220) to be available to the solar industry by 1985 even if the government takes no action to promote silicon production. If only 15% of the non-solar market

TABLE 4-4. COMPARISONS OF SILICON DEMAND FORECASTS¹

<u>Year</u>	<u>Non-Solar Market</u>	<u>Solar P.L. 95-590 Scenario</u>	<u>Market Median Scenario</u>	<u>Low Scenario</u>
1977	1128	8	8	8
1978	1533	16	16	16
1979	2042	60	31	31
1980	2357	122	45	30
1981	2680	211	113	57
1982	3056	420	217	146
1983	3415	816	387	258
1984	3815	1580	645	386
1985	4220	2760	980	577

¹Derived from "Silicon Material Outlook Study for 1980-85 Calendar Years," JPL Publication 79-110, November 1, 1979.

demand is available to the solar market, then the solar market can at best achieve a demand somewhere between the low and the median forecasts.

It is further unlikely that the price of silicon will drop dramatically when the advanced technologies are commercially available in 1986, since even those industries utilizing fully depreciated equipment can be expected to purchase as much low-cost silicon as possible. In the process of doing so, they can be expected to bid the price up to the marginal cost of production using the old process, which is \$40/kg. In fact, under free market conditions, it may take several years after the commercial availability of new technologies for sufficient numbers of new technology silicon plants to become commercially available and produce low-cost silicon for the solar industry. This delayed penetration for solar applications results from the increased ability to pay of the integrated circuit industry, this means that under free market conditions all non-solar capacity must be supplanted by the new technology before the price of silicon for solar cells will decline.

As a result, natural market forces cannot be relied upon to reduce the price of silicon for solar cells. Rather, the government must intervene in the marketplace in order to achieve an aggressive goal such as the penetration mandated by Public Law 95-590. Such intervention could take the form of:

- 1) Loan guarantees to silicon manufacturers to expedite the acquisition of new process equipment
- 2) Joint ownership of silicon production facilities
- 3) Tax credits for purchase of silicon production equipment
- 4) Favorable legislation for the verticle integration of solar cell manufacturing enterprises.

Although each of these measures may achieve some degree of success, the most promising options are those that guarantee a supply to the solar cell industry, and thus do not subject the industry to competition from other users of silicon. In fact, the commercial viability of photovoltaic energy -- and in particular the application of this technology to central stations -- depends upon the availability of low-cost silicon.

In summary, over the next decade the shortage of silicon may limit the commercialization of photovoltaics in the absence of government intervention. The nature and the timing of this intervention will play a major role in the commercialization strategy for photovoltaic central stations.

2. Lack of Industrial Infrastructure - A complete photovoltaics industry should provide everything from silicon for cells to maintenance for existing systems. Such a multi-faceted industry requires a complex infrastructure which takes time to develop fully. This lack of this industrial infrastructure restrains the speed with which photovoltaic market penetration can take place.

If a utility attempted to purchase a 100 MWe photovoltaic central station facility immediately, it could not be done within the existing industrial infrastructure. A silicon production plant would have to be built, since inadequate production capacity exists in the current market. Also, facilities for fabricating solar cell modules from the raw materials must be constructed. Finally, the engineering services needed to install large scale photovoltaic arrays must be developed along with the expertise necessary to integrate the arrays into the utility grid. Operating and maintenance personnel and procedures must also be obtained in order to keep the plant functional, which adds another unknown requirement. It

must be anticipated that such an infrastructure will develop only incrementally as the market place responds to an expanding photovoltaic industry.

Lack of an industrial infrastructure, however, does not appear to be a serious threat to photovoltaic progress in the near-term since market penetration will not be that aggressive. In the late 1980's and early 1990's, however, the expected rapid expansion of the photovoltaic market could be limited by the available industrial infrastructure and its ability to expand.

Demonstration projects, initial commercial systems, and eventually mass production will contribute to the gradual development of an infrastructure. To insure consistent growth of the industry, the Photovoltaics Program must take steps to ensure constant increases in the total annual U.S. purchase of photovoltaic systems each year. Failure to do so would lead to skepticism and caution in the industry rather than promote optimism and aggressive growth in a private industry. It is important to emphasize that sporadic federal involvement in market development would pose a serious threat to the evolution of a photovoltaic industrial infrastructure.

3. Lack of Standards and Codes - Although this barrier may only produce relatively minor disruptions in the growth of central station photovoltaics, it is a barrier that can be avoided with relatively little effort, thus leading to a much stronger photovoltaic industry.

Standards and codes include everything from building requirements to methods of collecting and sharing operational information. The lack of such standards could lead to confusion in the photovoltaic industry, and ultimately add to the lack of user confidence.

The federal government is now in a prime position to institute common standards and codes in the industry. Because the government is involved in most photovoltaic projects now, and will be involved in early central station projects, it is in a position to institute common standards that, if reasonable, will eventually be adopted by a growing industry. If the government delays until central station applications are commercialized, however, it would have to resort to regulation to impose standards and codes. This could ultimately lead to even more confusion which in turn will hamper that achievement of program goals. Therefore, a minimal effort in the near future that is designed to produce at least an initial set of codes which can be improved upon as operational experience is gained could yield the greatest benefits in the long run.

4. Large Land Requirements - The amount of land required for large central station photovoltaic plants is significant. For example, if photovoltaic collectors with a 10% conversion efficiency cover one-third of the plant area, a 100 MWe plant (small by electric utility standards) will require approximately 1.2 square miles. A one gigawatt plant will require 12 square miles.

Since there are potential early markets with enough land area for a photovoltaic central station facility, land area is not likely to be a problem in the near-term or the mid-term. If photovoltaics is to gain widespread commercialization with central station applications, however, positive steps must be taken to resolve the land area problem. Techniques for preserving and acquiring land or the rights to use land in or near urban areas must be developed.

Solving this problem requires studies of available land, land rights laws, and the possibility of federal land use incentives. However, since this is primarily a long-term problem, it should be given a low priority relative to the other barriers.

5. Environmental Impacts - Photovoltaic central stations are considerably more benign than conventional power with respect to overall environmental impact, and photovoltaic systems conform to the National Environmental Policy Act (NEPA). However, some issues have been raised concerning the effects of using large land areas for central station applications. For example, the impact of shielding the earth from the sun on a large scale could affect not only the land but weather patterns as well. Additional concerns have surfaced with respect to the environmental impacts of manufacturing photovoltaic cells on a large scale. The most prominent of these issues include:

- The safety of workers exposed to arsenic, cadmium, and other hazardous substances during the production of photovoltaic cells.
- The disposal of mining and plant wastes, including soluble metal chloride, hydrogen chloride, and other mercuric and acidic effluents.
- The generation of toxic gas during photovoltaic cell production, such as silicon dust, boron trichloride, and phosphine.

Most of the environmental hazards are long term in nature, and will develop only after considerable production of photovoltaic cells is established. The Office of Technology Assessment is investigating these potential problems. In the near-term and mid-term, the impact of these environmental issues on photovoltaic cell production is not expected to be significant in terms of either program delays or energy costs. Consequently, the resolution of these issues should not be afforded as high a priority as other barriers identified in this document.

6. Legislative Requirements - The Solar Photovoltaic Energy Research, Development, and Demonstration Act of 1978 (PL95-590) set three specific goals for the PV Program:

- (1) Cumulative production of 4 GWe by 1988
- (2) Average cost of one dollar per watt (1975 dollars) by 1988
- (3) Ninety percent user cost share in 1988.

The extent to which central station will contribute to the first goal needs to be established. Plans for complying with the third goal need to be analyzed, including the effects of such potential activities as federal price guarantees and similar innovative financing techniques.

Furthermore, specific regulations have been promulgated with respect to the Public Utility Regulatory Policies Act of 1978 (PURPA) which will have an impact on both the ratemaking policies and the worth analyses of utilities installing photovoltaic systems. Under existing regulations, a utility must adhere to federal standards regarding costing techniques, time-of-day/seasonal analyses, and load management. Procedural requirements contained in PURPA must also be addressed.

Finally, the impact of federal and state legislation and rulings on photovoltaic central station applications must be examined. On the federal level, the Powerplant and Industrial Fuel Use Act (PIFUA) has mandated a transition away from oil and gas to alternative energy sources. Similarly, individual states and public utility commissions (for example, the California legislature) have placed restrictions on the use of certain energy sources and technologies. The opportunities for central station photovoltaic applications, as well as potential inhibitions, need to be identified and analyzed on a continuing basis.

SECTION V

STRATEGY PRINCIPLES

A. PURPOSE

The purpose of a photovoltaic central station market development strategy is to accelerate what is likely to occur as a result of time and natural market forces -- the commercial use of photovoltaic energy systems in the electric utility industry.

As has been identified in earlier sections of this document, there is a need for alternative energy sources in this country, and part of that need can ultimately be satisfied by photovoltaics technology. Currently, however, there is a gap between market needs and the product that photovoltaics can supply. In that gap reside the barriers discussed in the previous section of this document. A market development strategy must be targeted towards breaking those barriers and bridging that gap.

B. DEFINITION

A market development strategy is a conceptual approach, which when planned and implemented effectively, initiates a series of activities designed to bring a technology from its existing state to that of a mature, commercialized technology.

Figure 5-1 places commercialization efforts in perspective with the evolution of solar technology from infancy to maturity. The technology flow shown in Figure 5-1 forms the basis for the development of a market development strategy. In general, a strategy is designed to achieve a given objective. That objective generally defines the target of the strategy, which in this case is the electric utility market. In addition to the target

TECHNOLOGY FLOW

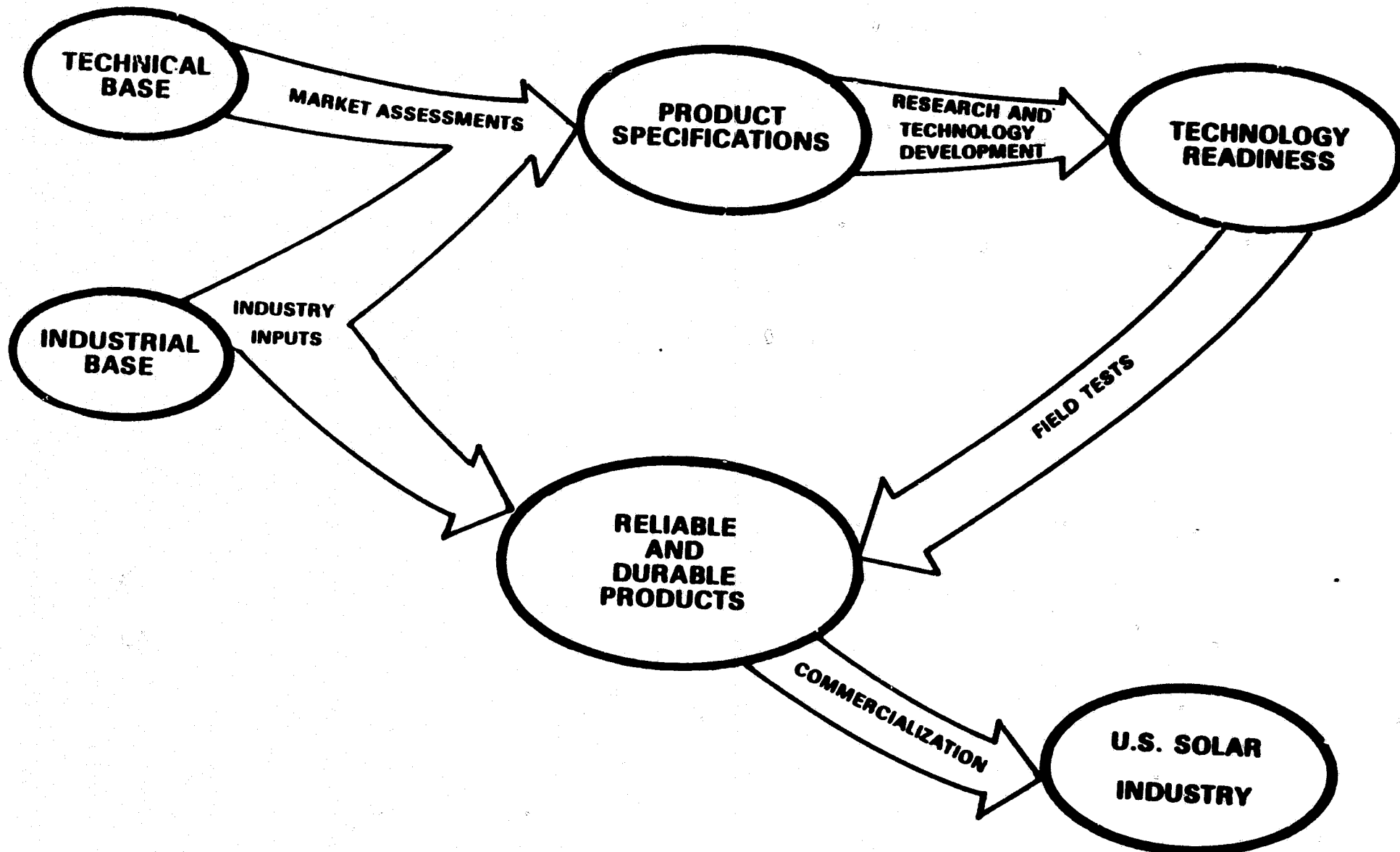


Figure 5-1

market, a strategy includes a set of activities designed to bridge the commercialization gap and reach the objective. If specific quantitative goals are set, then the activities must be phased in accordance with meeting the stated goals. A strategy, then, consists of 3 basic elements:

- Target (market sectors)
- Selected Activities
- Phasing of Activities

When this flow takes place in private industry, the basic elements of the flow are market assessment, product development and an advertising campaign, the latter being market development. In the federal government, however, there is a much broader range of activities which can be implemented in a market development strategy (see Figure 5-2). Therefore, market development strategies are much broader in scope in the government than are those in private industry. Because of this, strategy selection processes must be examined to determine the appropriate federal strategies.

C. STRATEGY DEVELOPMENT PROCESS

Of the three basic elements of a market development strategy -- targets, activities, and phasing -- the selection of activities is generally the key strategy selection issue. Market targets are generally straightforward, and phasing merely changes the time frame of the emphasis of a strategy. The activities, however, are chosen to specifically address certain market penetration barriers. These activities determine the federal role in the commercialization effort.

Figure 5-2 displays the activities in which the federal government can be involved. Two product improvement activities -- Technology Development and Research and Development -- are included in the list even though these

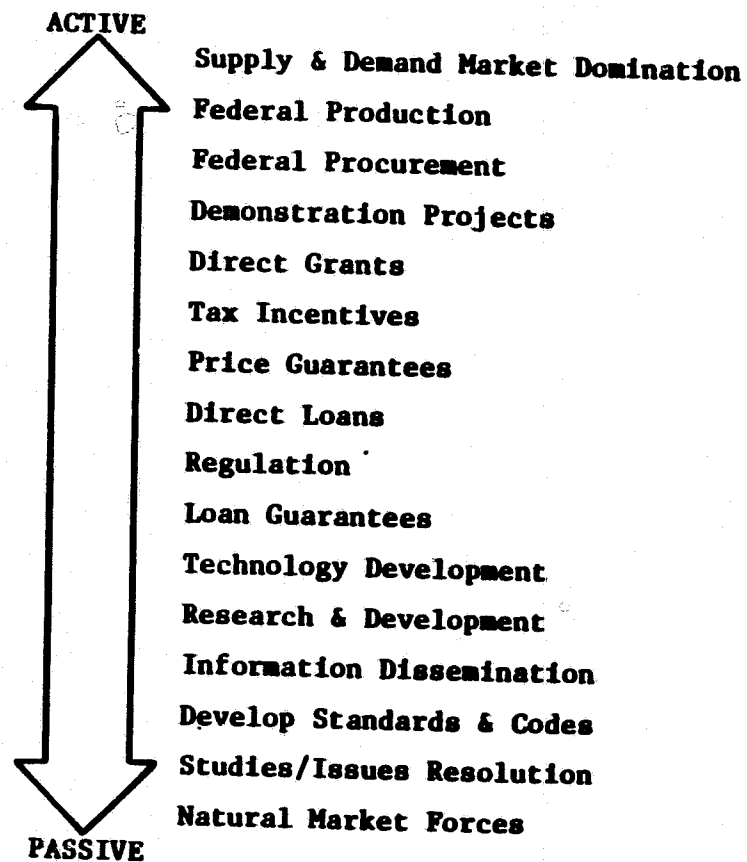


Figure 5-2
Federal Roles

activities precede market development in the technology flow. They are included because a market development strategy can depend on these efforts being carried out as part of a product improvement strategy. All the other activities in Figure 5-2 are commercialization activities, and are discussed in Section IV. These 14 activities can be grouped into four general categories:

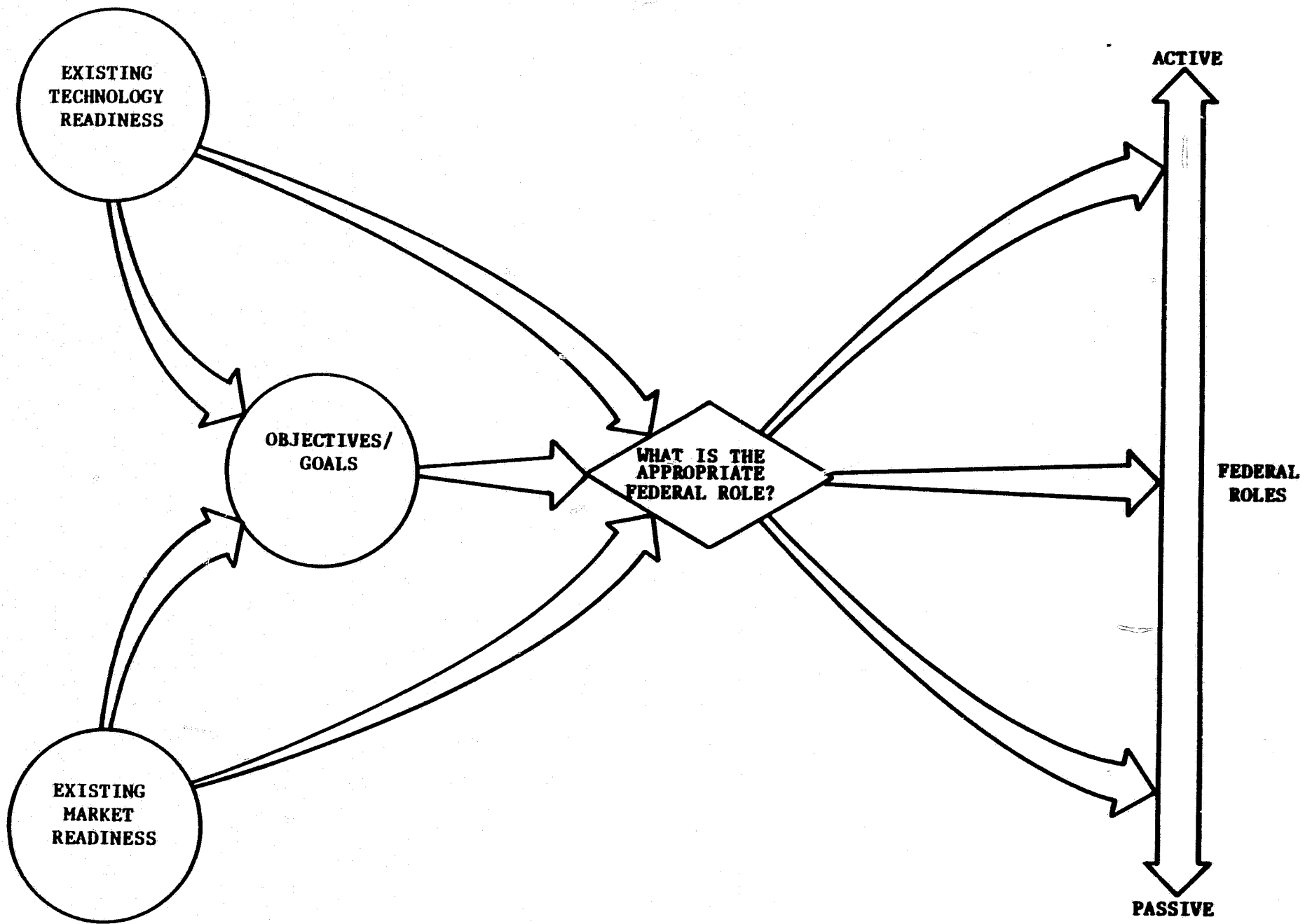
- Federal Procurement
- Financial Incentives
- Regulation
- Information Service

Figure 5-3 displays graphically the process for selecting the appropriate federal activities. Two environmental givens, market needs and technology status, define the supply-demand gap that must be bridged. The objectives may suggest a method for overcoming these barriers, and provide an indication of the extent the market can be penetrated. For a given set of environmental conditions, then, several strategies can be developed based on the objectives defined.

D. STRATEGY ELEMENTS

The strategy development process discussed above should be used to extend the general Photovoltaic Program objective to the central station sector by bringing photovoltaic energy systems to a state of market penetration. The following three strategy elements can be identified as key aspects of any central station market development strategy:

- Information Program - In order to collect and disseminate data and information, this program should have data accessibility, data consistency, an interactive information flow, and mobile demonstrations. This important program is discussed in more detail in Section IV.B.2.



Federal Role Determination

Figure 5-3

- Hardware Testing Program - This program should include a field test and procurements or a set of financial incentives to stimulate hardware purchases. This program serves the dual purpose of stimulating the market for photovoltaics while providing information on the operational characteristics of the system. By stimulating the market for photovoltaics, a hardware testing program would serve to fortify the industrial infrastructure supporting the photovoltaics market, which would encourage the development of mass production techniques for module production. This measure would therefore assist in initiating the cost reduction/demand augmentation cycle that is key to the commercialization of this technology. Also, by providing information on the operational characteristics of photovoltaic systems, a hardware testing program would serve to diminish the uncertainty that impedes the acceptance of such systems by utilities. The development and dissemination of the more definitive cost and operational data supplied by this program should be conducted in conjunction with the information program described above.
- Issues Resolution Program - A comprehensive set of studies designed to address the following issues: materials availability, the value of photovoltaics to utilities (including such issues as the benefits of the modularity of photovoltaics and of the short construction periods required for photovoltaic power plants), balance of system costs, financing options, the value and risks of instituting federal price guarantees, the development of standards and codes, land use problems, environmental impacts, legislative requirements, and Public Utility Commission or local government policies and influence. These issues are addressed in Section IV.

These three key strategy elements would contribute to any central station commercializations effort.

The selection of these three strategy elements is based on a general assessment of central station market needs with respect to the general Photovoltaic Program objective and the technology status. Basically, the market sector requires three conditions for penetration:

- User Confidence
- Affordability
- System Availability

When compared to the status of central station systems technology today, none of the three market needs can be satisfied. There is a general lack of confidence on the part of the electric utilities (as discussed in Section III.B), the systems are not cost competitive, and no systems are available today. Section IV contains a discussion of these barriers, including a range of potential activities that could span the demand-supply gap in light of the stated general objective of achieving market penetration. Resolving the lack of user confidence requires an information program coupled with hardware projects. Resolving the affordability issue requires financial incentive packages that stimulate market demand, thus reducing costs to entry market users and generally reducing costs as a result of increased production. Systems availability must be addressed by creating a market demand so that an industrial infrastructure will develop.

In summary, the three basic strategy elements, based on one general objective, are designed to bridge the gap from:

- lack of user confidence to an aggressive market demand
- non-affordability to competitively priced systems
- an infant industry to the development of an industrial infrastructure.

E. OBJECTIVES AND STRATEGIES

The preceding portion of this section has provided a set of strategy principles which, when applied to specific central station objectives, can produce specific central station market development strategies and implementation plans.

For example, consider the following three alternative objectives:

- 1) to increase market demand in the near term, assuming that expansion of the market will provide a bridge to energy saving markets.
- 2) to de-emphasize near-term goals in favor of developing U.S. energy saving markets in the twentieth century.
- 3) to increase production volume in the near term, assuming that price reductions will stimulate market demand and lead to energy saving markets.

Incorporating objective (1) into the strategy development process results in a strategy (1) that consists of the three key strategy elements: user incentives, information programs, and issues resolution. The emphasis of strategy (1) is on hardware procurement in the near term.

Objective (2) yields a similar strategy. The near term emphasis of strategy (2), however, is on issues resolution rather than on hardware. Hardware penetration will, of course, be emphasized in the long term. The basic difference between strategies (1) and (2), then, is the timing of the activities.

Objective (3) yields a slightly different strategy. This objective calls for emphasis on near-term production. Therefore, objective (3) will require producer incentives in the near term to stimulate production, while still maintaining the information and issues resolution programs.

F. CONCLUSIONS

The basic conclusion of this section is that the Photovoltaic Program needs to establish an objective, or set of objectives, for photovoltaic central stations. Given the establishment of an objective by the program, the strategy principles outlined in this section can be applied to the objective(s) to develop an implementation plan for the commercialization of central station photovoltaics.

The key elements of alternative strategies have been delineated, and, when placed within the context of an objective for photovoltaic central stations, can readily be assimilated into a cohesive plan for the attainment of central station market development.

In addition, there are some unresolved issues which, although already discussed in this document, are of sufficient importance to be highlighted below:

- o Institutional Issues - How can such entities as state Public Utility Commissions and state governments be persuaded, through regulatory practices, to embark on an aggressive program to encourage the use of solar energy by the electric utilities?
- o Solar Tax Credits - Can solar tax credits now offered to businesses and private individuals be extended to include electric utilities?
- o Price Guarantees - To what extent and at what risk can price guarantee incentives policies be pursued?
- o Power Marketing Administrations - What role can the PMA's play in developing the central station market?
- o What are the specific objectives and goals of the central station program?

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